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Magnetic Character of Very Thin Permalloy Films

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Magnetic Character of Very Thin Permalloy Films

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The quasistatic magnetic characteristics of thin Permalloy films have been investigated using a sensitive automatic magnetic torque balance. The most striking feature of the many films investigated in the thickness range below 250 Å is their similarity to thicker films. The data for K are essentially constant until about 80 Å where it drops quickly and smoothly to zero at about 30 Å. The value of the magnetization as a function of thickness supports that of Seavey and Tannenwald, obtained from microwave resonance absorption. The value of the longitudinal coercive force as a function of thickness exhibited a spread of values typical of thicker films of this particular fabrication procedure. Slight dependence on thickness could be observed in general agreement with the data of Behrndt.

WITH the intent of observing the quasistatic magnetic character of thin Permalloy films as the thickness becomes small, a very sensitive magnetic torque balance has been constructed.[1] It uses the principle of the Croft *et al.*[2] and Boyd[3] automatic torque balances but with a unique fused silica suspension and servo system that allows an increase in the sensitivity by about three orders of magnitude to 10^{-6} dyn-cm, and a resolving time of a fraction of a second. The torquemeter movement, torsion fibers, and fixed supporting and tensioning members have all been fabricated from fused silica to provide an integral, mechanically-stable assembly. This construction allows reduction of the size and weight of the assembly. The extremely short light path (9 mm) and rugged construction ensures that the light and photocell vibrate together at least for low frequencies. The light weight (80 mg including the sample) and low moment of inertia of the torquemeter movement allow a tighter force-balance loop and improve response time. Both factors tend to minimize the low frequency disturbances allowing the higher frequencies to be electronically controlled. All significant mechanical sources of error are eliminated by the use of small (5μ) suspension fibers. A high-gain servo loop ensures that the sample is stationary within 0.11 mrad during a measurement. The torquemeter can be calibrated as a mass balance using a known weight, thus allowing an absolute measure of torque.

The films were made by vacuum evaporation from a melt of nominal composition 80% Ni and 20% Fe. The thin glass substrate was maintained at 300°C in a uniform magnetic field of 50 Oe during evaporation. The evaporation rate was maintained at about 1000 A/min in a vacuum of about 10^{-6} mm Hg with the thickness controlled by shutters. Four films were made at a time with some very thin and others in the normal thickness range. Five pairs were made which varied from this procedure in that one of each identical pair was immediately overcoated with aluminum. The size of all samples was confined to 1-cm-diam spots during evaporation by a thin copper mask. The thickness and chemical composition of all films were measured by x-ray fluorescence. All samples used were 76%± 1.0% Ni. Thicknesses are expected to be correct to 5%. All magnetic investigations were made prior to the x-ray measurement.

It is generally assumed, as was first done by Smith,[4] that the classic Stoner–Wohlfarth model[5] used to describe single domain particles also describes the anisotropy in thin films. The value of the anisotropy constant K can be evaluated by observing the torque perpendicular to the plane of the film caused by a field in the plane at some angle to the anisotropy axis. It is customary to plot the maximum torque for a complete cycle of the field as a function of the inverse of the field and extrapolate to infinite field.[6] Such a procedure seems unnecessary for most films as has been noted by others.[7] The value of K was determined here by using three field values (15, 25, and 30 Oe), with the requirement that the maximum torque be the same for all three field values.

The observed value of K as a function of thickness is shown in Fig. 1. The observed scatter is the usual variability found in the anisotropy and is not due to measurements which, except for the thinnest film, are made with an over-all accuracy better than 5%. In spite of this scatter, it can be seen that the anisotropy is essentially constant for film thicknesses greater than 80 Å. Below about 80 Å, the magnitude of K drops to zero somewhere around 30 Å. As will be mentioned later, this drop matches very closely the reduction in M as the film thickness decreases but is slightly faster so that the value of the anisotropy field, $H_K=2K/M$, drops below about 80 Å.

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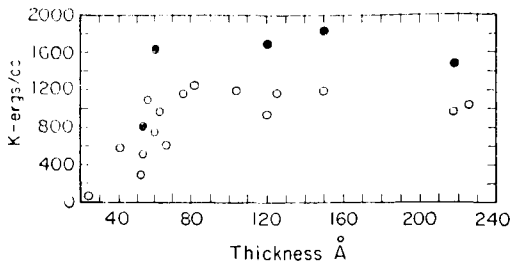

FIG. 1. The anisotropy constant assuming uniaxial anisotropy for Permalloy films is plotted as a function of film thickness as measured by x-ray fluorescence. The open circles are for uncoated films and the solid circles are for samples coated with a film of aluminum immediately after deposition.

It is interesting to note the solid points on Fig. 1. They represent a sample made side by side with the sample of identical thickness immediately below. The solid point of this pair was immediately overcoated with aluminum as previously mentioned. In each case, the magnitude of the anisotropy of the coated film is considerably greater than that of the other member of the pair. It is clearly premature to draw any conclusion from such a cursory observation in a system with as much variability as this system has.

Generally (on the films being discussed here) there is very little or no rotational hysteresis loss until the reduced field, $h=HM/2K$, is in the range $1>h>0.5$; or, if $h_c<0.5$, then the range is $1>h>h_c$. The rotational hysteresis loss compares very favorably[8] with that predicted by the Stoner–Wohlfarth model for films where $h_c>0.5$. For films where $h_c<0.5$, the fit to the Shtrikman–Treves[7] model is only fair with generally more loss being predicted than observed.[9]

By placing the sample on an auxillary hanger, it is possible to measure the torque with the torsion axis parallel to the plane of the film caused by a field perpendicular to the torsion axis and at some small angle to the plane of the film. As long as the field is small compared to $4\pi M$, the torque will be a linear function of the field for a given sample and angle allowing the calculation of the magnetization. The magnetization as a function of thickness observed here seems to follow the data of Seavey and Tannenwald[10] obtained from microwave resonance absorption spectra. It should be mentioned that the films measured here were measured outside of the vacuum system and were uncoated except for those few which had only about 10% higher magnetization than the uncoated mate. This increase was within the spread observed from samples made in various evaporation. A simple oxidation mechanism for the marked increase in K does not fit the data for M. It should also be mentioned that this low field method for the measurement of M would detect, as a nonlinear relationship between the torque and the field, any demagnetizing field associated with the film existing as isolated clumps. Since all films presented here exhibited linearity, it can be concluded that clumping need not take place in films as thin as 30 Å.

By reversing the field, the torque method affords a very sensitive measure of the coercive force of the sample.[11] The coercive force, as a function of thickness was observed for a number of samples. The conclusion is that the coercive force is essentially independent of thickness. There is some evidence that the coercive force increases slightly with thickness in the range 30 to 400 Å. If such an effect does exist, it is clearly smaller than the other factors that influence the coercive force during a normal evaporation. This result is in good agreement with Behrndt[12] and is in disagreement with the conclusion of Bradley and Prutton[13] where they expected a sharper increase in the coercive force in this thickness range.

It can be concluded, then, that very little happens to the quasistatic characteristics as the film thickness reduces to zero. The magnetization and the anisotropy fade away smoothly. The latter decreases slightly faster causing the anisotropy field to decrease. The coercive force and the squareness remain essentially constant over the range of thickness investigated. The anisotropy axis is well defined and the reduced rotational hysteresis loss seems to follow the various models proposed as least as well as for thicker films.

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